in an excursion to Crowhurst. Open-air work gives a genuine foundation to the study of geography, and thereby that essential factor, the map, can be properly understood.

Public Schools' Science Masters' Association.

The salient features of the annual meeting, held at Westminster School on January 14, were:—(1) the address from Prof. H. A. Miers, F.R.S.; (2) the instructive exhibition of apparatus; (3) the discussion on the position of mechanics in the physics course; (4) the repeated expression of the need for cooperation between the masters responsible for mathematics and physics respectively.

Prof. Miers took as his subject the order in which scientific ideas should be presented. He deprecated any rigid division of science into subjects, and believed that harm had resulted from attempts to keep mathematics, physics, and chemistry apart from each other, and to confine them to separate teachers. He desired to leave freedom to the individual teacher as regards method, but felt that as regards order there should be more system in our science teaching. In other subjects there was an advantage in having a recognised order based upon prolonged experience, and science should stand upon the same level as languages and mathematics in our schools, and should form an integral part of any liberal education. It was not easy to find out at the moment what the pupil understood of the instruction, and where he had succeeded in analysing the difficulty of a pupil he generally discovered that he himself was at fault in having presented ideas in the wrong order, and assumed something which was not yet familiar to the pupil. He found a useful guide to the proper order in the succession in which the ideas of a science had been developed in its past history.

Prof. Miers advocated nature-study in the wide sense; the boy should be taught to notice the ordinary objects and events of his own world, and to draw scientific nourishment therefrom, including in his intelligent observation all that was going on around, and not merely the processes of nature familiar in country life. If only the ordinary boy could get into his head the notion that science was the intelligent study of ordinary things, he would cease to regard it as a mere educational task. It was unwise, if not impossible, to teach chemistry and physics as independent subjects. In the preparatory school the boy should be trained in observational work, which would impart information useful in the experimental science that was to come next. The systematic teaching at a public school should from the outset be experimental, and the spirit of inquiry should be cultivated, and scientific dogmatism guarded against.

Coming to the university teaching of science, we had now to deal with mature minds, and the spirit of research should absolutely dominate the teaching. There was nothing better for encouraging research than natural history, which was admirably suited for advanced study at the university. Original papers were more stimulating than text-books, and there is need for an English series reproducing the original researches of highest importance, perhaps with the translation of archaic expressions into modern equivalents. Lectures should follow the historical order, laboratory work the method of research.

Prof. Armstrong felt it to be a deplorable fact that science had lost ground in public estimation. We felt the absence of Huxley and Playfair, and it rested with the public schools to carry the banner forward. The Davy-Faraday laboratory had, with one exception, failed to attract the gilded youth, fired with enthusiasm for science by their work in public schools. We must teach so as to excite more interest, so as to make that interest more continuous and permanent, and so as to cultivate, not powers of observation only, but the faculty of keen, intelligent criticism also. He held that Germany had achieved her position owing to the cultivation of originality by her universities.

The other papers read during the meeting were:—(1) the educational value of mechanics, by Mr. C. F. Mott (Giggleswick); (2) the teaching of practical mathematics, by Mr. H. Wilkinson (Durham); (3) scheme for laboratory work in physics, by Mr. Cumming (Rugby); (4) a suitable physics curriculum for the first and second years, by Mr. W. E. Cross (Whitgift); (5) the compulsory teaching of elementary physics to junior forms, by Mr. J. M. Wadmore (Aldenham).

In the course of the discussions, it was pointed out that there is a great leakage from schools of boys who are under the proper leaving age, and that such boys necessarily receive little scientific education. There was no lack of enthusiasm for science on the part of boys who fulfilled the course of instruction. The fact that boys were promoted in many schools without regard to their science work placed difficulties in the way, such as were met by re-arranging the schools in sets in the case of mathematics. The study of scientific mechanics might be postponed until boys had obtained some experience in general experimental physics; practical work in heat could be introduced earlier. Boys should be allowed to use modern electrical plant, such as the cheaper voltmeters and ammeters now available through being put on the market for motorists. Mr. Cross advocated the abandonment of the usual exercises in mensuration and Archimedes's principle, and the substitution of a course of experimental construction of working cranes, &c. He would devote the first two years to such work, which stimulates interest and leads to a grasp of principles, *e.g.* the inquiry into the transmission of power by belts leads to true notions about energy and friction. It is a pity that there was little criticism of this interesting and unorthodox paper, for there is no doubt that most boys want to know "how it works"; moreover, the course which Mr. Cross outlined can readily fulfil Prof. Miers's requirement that the application of the instruction to everyday life should be straightforward. The relative merits of working collectively or individually in the laboratory were discussed, and Mr. Cumming claimed that the former system proved successful at Rugby. In summing up the discussion, Prof. Miers remarked upon the extreme diversity of methods adopted in different schools.

The exhibition of apparatus attracted well-deserved attention. Several dealers in apparatus, and some of the leading publishers, sent extensive exhibits, but the most gratifying, and in many respects the most instructive part of the exhibition was the ingenuity of the home-made contrivances sent from a good number of schools. We must congratulate and thank those responsible, and particularly Mr. D. J. P. Berridge, to whose organisation much of the success of this feature of the meeting was due. There were so many items of interest that it is impossible to describe them all, and it seems invidious to select. On the score of daring simplicity, we may perhaps award the palm to a motor armature shown by Mr. C. J. L. Wagstaff, which consisted of a bottle-cork, a few turns of insulated wire, and a dozen pins. Dr. T. J. Baker reached the acme of simplicity in his supports for prisms, lenses, &c. These were mounted by being stuck in their appropriate positions into lumps of plasticine—*voilà tout*! We would suggest to the management the advisability of printing a large number of copies of the catalogue; they might be put on sale; in any case their wider diffusion would help to improve experimental teaching by simple apparatus of homely invention and make.

G. F. Daniell.

THE INTERDEPENDENCE OF MEDICINE AND OTHER SCIENCES.[1]

An historical sketch, necessarily brief and inadequate, of some of the principal phases in the reciprocal relations between medicine and the physical sciences, up to the time when the latter became fully independent at the close of the seventeenth century, will show with what propriety medicine has been called the "mother of the sciences."

Physical science has derived from the Greeks no such extensive records of sound observation and experience as those which medicine has inherited from the writings of Hippocrates and his followers. Physical theories embodied in the speculations of the nature-philosophers concerning the constitution and properties of matter furnished the starting point for the Hippocratic doctrine of the four humours and other generalisations, but these theories sat so lightly upon Hippocrates that his name is attached to that method of medical study which rejects dogma, authority, and speculation, and confines itself to the observation and record of clinical facts. As Gomperz in his admirable work on the "Greek Thinkers" has clearly pointed out, the age of enlightenment in scientific thought was inaugurated by Hippocrates and his medical contemporaries.

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[1] From an address delivered by Dr. W. H. Welch, professor of pathology, Johns Hopkins University, Baltimore, as the retiring president of the American Association for the Advancement of Science, at Chicago, December 30, 1907.

The influence of physical theories upon medical thought in antiquity can be traced, not only in the humoral doctrines of Hippocrates and of Galen, but also in rival schools, and especially in the so-called methodic school founded upon the atomistic philosophy of Democritus, which is so interesting in the history of scientific theories. As this school produced such admirable physicians as Asclepiades, Soranus, and Aretæus, it is to be regretted that their solidistic pathology was so completely displaced by the authority of Galen.

The large body of medical knowledge and doctrine which had grown up during the six centuries since Hippocrates was further developed and fixed by Galen at the end of the second century after Christ into a system not less complete in its field, nor less satisfying to the minds of men for nearly fifteen centuries, nor scarcely less remarkable as a product of the human mind than the physical and philosophical systems of Aristotle. Within their respective spheres the system of doctrine of each of these great men has exerted a similar dominating influence upon human thought, and has met a similar fate through influences almost identical.

The great awakening of western Europe, marked by the revival of learning and the Reformation, stirred the long dormant spirit of inquiry and led to revolt against authority, a fresh outlook upon a wider world, the study of original sources, the questioning of nature at first hand, and the search for new knowledge in all her kingdoms. The seat of learning was transplanted from the cloisters to the universities, which multiplied and flourished in the sixteenth and seventeenth centuries as never before.

In the sixteenth century practically all the valuable contributions to botany and to zoology were made by physicians, so that natural history scarcely existed apart from medicine. Of the medical contributors to botany, it must suffice to mention the names of Brunfels, Fuchs, Dodoens, Gesner, and, above all, Cesalpinus, who has been called "the founder of modern scientific botany," the most important name before John Ray in the history of systematic botany, and a distinguished figure likewise in medical history. Of names associated with the history of zoology in this century, the most important are those of the physicians, Conrad Gesner, a marvel of encyclopædic learning, and Aldrovandi, who ranks with the founders of modern zoology and comparative anatomy; of lesser lights Edward Wotton may be singled out for mention as the pioneer English zoologist. He was doctor of medicine of Padua and of Oxford, president of the Royal College of Physicians, and physician to Henry VIII.

A name of the first rank in the history of science is that of the physician, Georg Agricola, who founded before the middle of the sixteenth century the science of mineralogy, and developed it to a state where it remained for nearly two hundred years without important additions.

The student of medical history who takes up a history of physics will probably be surprised to find how many of the contributors to the latter subject in the sixteenth century were physicians, and that among these are such old friends as Fernel and Fracastorius, whom he has identified so intimately with the annals of his profession. It is to be presumed that he already knew that the most famous of all, Copernicus, was a doctor of medicine of Padua, and practised the medical art gratuitously among the poor in Frauenburg.

Far more important for the subsequent history of science than any relations between medicine and physics at this period was the union between medicine and chemistry effected by Paracelsus, and strengthened by van Helmont and Sylvius in the following century, a union so intimate that for nearly a century and a quarter chemistry existed only as a part of medicine until freed by Robert Boyle from bonds which had become galling to both partners. The story of this iatro-chemical period, as it is called, has been told by Ernst von Meyer in his fascinating "History of Chemistry" in a way not less interesting to the student of medicine than to one of chemistry, and should be there read by both.

William Gilbert, second in importance only to Galileo among the creators of experimental science, the founder of the science of magnetism, and a significant name in the history of electricity, was fully identified with the medical profession, being the most distinguished English physician as well as man of science of his day, physician to both Queen Elizabeth and James I., and president of the Royal College of Physicians.

Galileo's younger contemporary, William Harvey, the discoverer of the circulation of the blood, occupies in the history of experimental science an independent position quite unlike that of the other experimental physiologists of the century. These other physicians, as Sanctorius, Borelli, Lower, Mayow, consciously took possession of the method of experiment as a powerful and newly discovered instrument of research, and were swayed in all their physiological work by the discoveries of the physicists. Not so Harvey, who was influenced but little by contemporary physical science, and is linked on, not to Galileo or to Gilbert, as exemplars of experimentation, but in a very direct way to the experimental physiologist, Galen, and to Aristotle, as well as to the Italian anatomists of the preceding century. Harvey's genuinely scientific mind was in greater sympathy with Aristotle than with the essentially unscientific Lord Bacon, who was his patient, and of whom he said, "He writes philosophy like a Lord Chancellor."

Descartes was an anatomist and physiologist as well as philosopher, mathematician, and physicist, and John Locke, the other great liberator of thought in this century, was educated in medicine, practised it, and, like Boyle, accompanied Sydenham on his rounds. Kepler studied the pulse, contributed to physiological optics, and calculated the orbits of the planets. Borelli was an important mathematician, physicist, and astronomer, as well as one of the greatest physiologists and physicians of the century. Bartholinus was also professor of mathematics as well as of medicine, and discovered the double refraction of Iceland spar. His even more remarkable pupil, Steno, left a name memorable in geology and palæontology, as well as in anatomy and physiology, and died a bishop of the Roman Catholic Church. Mariotte, a pure physicist, discovered the blind spot in the retina. Boyle anatomised, experimented on the circulation and respiration, started chemistry on new paths, and perpetuated his name in attachment to an important physical law. Hooke, most versatile of all, claimed priority for a host of discoveries, and did, in fact, explore nearly every branch of science with brilliant, though often inconclusive, results. Malpighi was an investigator equally great in vegetable and in animal anatomy and physiology, and what a glorious time it was for the microscopists, like Malpighi, Leeuwenhoek, Swammerdam and others, who could immortalise their names by turning the new instrument on a drop of muddy water, or blood, or other fluid, or a bit of animal and vegetable tissue!

After the seventeenth century in Europe the natural sciences, though often cultivated by those educated in medicine and practising it, were independent, and followed their own paths, which, however, communicated by many by-ways with the road of medicine and with each other.

Botany and zoology acquired their independent position probably more through the work of Ray and Willughby than by that of any other naturalist. Botany, however, remained for more than a century still mainly in the hands of physicians. An interesting chapter in its history is the story of the various apothecaries' and other botanical gardens established through the efforts of physicians, and conducted by them primarily for the study of the vegetable materia medica. From such beginnings has grown the Jardin des Plantes in Paris, started by two physicians, Herouard and la Brosse, in 1633, into the great museum of natural history made by Buffon, Cuvier and others as famous for the study of zoology as by the de Jussieus and by Brongniart and his successors for botany. Less humble was the foundation of the British Museum and its appanage, the great Museum of Natural History in South Kensington, the gift to the nation of his valuable collections in natural history and other departments by Sir Hans Sloane, a leading London physician in the first half of the eighteenth century.

Aspects of my subject, full of interest, which I can now barely touch upon, are the influence of previous medical or biological training upon the work of a physicist or chemist, and closely connected with this the extent to which purely physical problems have been approached from the biological side. Call to mind how the central physical and chemical problem of the eighteenth century, the nature of combustion, was throughout this period intimately associated with the identical physiological problem of respiration, and how John Mayow in the seventeenth century, approaching the subject from the biological side, reached a conclusion in accord with that fully demonstrated a century later by Lavoisier, who thereby opened a new era for physiology as well as for chemistry. For the first time clear light was shed upon the function of respiration, the nature of metabolism, and the sources of animal heat, and such physical interest was attached to the study of these physiological phenomena that physicists of the rank of Laplace, in association with Lavoisier, Dulong, W. E. Weber, Magnus, A. C. Becquerel, Hirn, Regnault, and of course Helmholtz, have all made valuable contributions to the elucidation of these subjects.

The study of electricity, especially after the physiologist Galvani's epochal discovery, more correctly interpreted by Volta, engaged the attention of physicians and physiologists scarcely less than that of physicists. The latter became greatly interested in animal electricity, a subject partly cleared up by the physicists Ritter and Nobili, but mainly by the physiologist Du Bois Reymond.

There is no more striking illustration of the correlation of two apparently distinct lines of approach to the same problem than the attack from the biological and from the purely physical sides upon the thermodynamic problem, which is as fundamental for biology as for physics. The conception of the principle of conservation of energy was supplied independently and almost simultaneously, on the one hand, by students of the conditions of mechanical work done by the animal machine, and on the other by investigators of technical machines. Much of the essential preliminary study was on the biological side by Boyle, Mayow, Black, and Lavoisier. Mainly from the same side the physician and physicist, Thomas Young, first formulated the modern scientific conception of energy as the power of a material system to do work. Davy and Rumford contributed, and from the physiological side Mohr, Mayer, and Helmholtz, and from the purely physical side, after preliminary work by Poncelet and Sadi-Carnot, Joule, Thomson, and Clausius reached the same grand conception. The first to enunciate clearly and fully the doctrine of the conservation of energy and to measure the unit of mechanical work derived from heat was the physician J. R. Mayer. Joule's work completed the demonstration, but Mayer's name is deservedly attached to this principle by Poincaré and others, as Lavoisier's is to that of the conservation of mass, and Sadi-Carnot's to the principle of degradation of energy. As regards this last principle, it is almost as interesting to biologists as to physicists that in the so-called Brunonian movement, discovered by the physician and more eminent botanist Robert Brown, and the subject of interesting physical investigations in recent years, we behold an apparent exception to the principle of degradation of energy, such as Clerk Maxwell pictured as possible to the operations of his sorting demon.

I must forego further citation of examples of this kind of correlation between the work of physicists and of physiologists, and leave untouched the chemical side, which is much richer in similar illustrations. The significance to organic chemistry of the synthesis of urea by Wöhler, and to agricultural chemistry of the bacteriological studies of nitrification in the soil and fixation of nitrogen in plants, will perhaps indicate how large and fascinating a field I must pass by.

The light which has transformed the face of modern practical medicine came, in the first instance, not from a physician, but from a physicist and chemist, Pasteur. The field of bacteriological study thus disclosed was placed on a firm foundation and thrown open to ready exploration by Robert Koch, and thereby that class of diseases most important to the human race, the infectious, became subject in ever-increasing measure to control by man. Thus hygiene and preventive medicine, through their power to check the incalculable waste of human life and health and activities, have come into relations, which have only begun to be appreciated, with educational, political, economic, and other social sciences and conditions, and with the administration of national, State, and municipal governments. It is an especial gratification to record the stimulating recognition of these relationships by the social and economic section of this association, in which was started a year and a half ago a movement for public health, particularly as related to the Federal Government, which has already assumed national significance.

To the marvellous growth of the medical and other sciences of living beings during the past century, and especially in the last fifty years, physics and chemistry and the application of physical and chemical methods of study have contributed directly and indirectly a very large and ever-increasing share. In many instances there is no telling when or where or how some discovery or new invention may prove applicable to medical science or art. Who could have dreamed in 1856 that Sir William Perkin's production of the first aniline dye should be an essential link in the development of modern bacteriology, and therefore in the crusade against tuberculosis and other infectious diseases? As Robert Koch has said, it would have been quite impossible for him to have developed his methods and made his discoveries without the possession of elective dyes for staining bacteria, and colouring agents of no other class have been discovered which can serve as substitutes for the anilines in this regard. And how much assistance these dyes have rendered to the study of the structure and even the function of cells! If we trace to their source the discovery of Röntgen's rays, which have found their chief practical application in medicine and surgery, we shall find an illustration scarcely less striking.

No important generalisation in physical science is without its influence, often most important, upon biological conceptions and knowledge. I have already referred to the great principles of conservation of mass and of energy which are at the very foundation of our understanding of vital phenomena. Although we cannot now foresee their bearings, we may be sure that the new theories, regarding the constitution of what has hitherto been called matter, will, as they are further developed, prove of the highest significance to our conceptions of the organic as well as of the inorganic world.

The ultimate problems of biology reside in the cell. Whatever the future may hold in store, at the present day only a relatively small part of these problems are approachable by physical or chemical methods, and the day is far distant, if it ever comes, when cellular physiology shall be nothing but applied physics and chemistry. We cannot foresee a time when purely observational and descriptive biological studies, which to-day hold the first place, shall not continue to have their value. They represent the direction which makes the strongest appeal to the great majority of naturalists. The broadest generalisations hitherto attained in biology, the doctrine of the cell as the vital unit and the theory of organic evolution, have come from this biological, as distinguished from physical, direction of investigating living organisms, and were reached by men with the type of mind of the pure naturalist, who loves the study of forms, colours, habits, variations, adaptations, inheritances of living beings.

It is well that the sciences of nature hold out attractions to so many different types of mind, for the edifice of science is built up of material which must be drawn from many sources. A quarry opened in the interest of one enriches all of these sciences. The deeper we can lay the foundations and the farther we can penetrate into the nature of things, the closer are the workers drawn together, the clearer becomes their community of purpose, and the more significant to mankind the up-building of natural knowledge.